EMC cement containing 70% fly ash Class F – Performance Data

The data related to the early-age strength development of the standard mortar (binder-to standard sand ratio 1:3, and water-to-binder ratios required to obtain the similar consistency) produced with EMC cements containing 70% FA Class F and 30% PC. Table also contains the data for reference PC and PC/FA mixes obtained by CCRL Approved Testing Facility.

Type of cement	**w/ B**	**Compressive strength, psi Curing time, days**			
		1	**3**	**7**	**28**
PC *	0.48	1492	3858	4358	5601
*EMC70fa***	0.42	***1595***	***3335***	***4060***	***5600 (38.6 MPa)***
*EMC70fa***	0.38	***1812***	***3400***	***4350***	***6163(42.5MPa)***
PC + 20% FA*	0.46	943	2957	3430	5195
PC + 40% FA*	0.44	547	2187	2563	4294

*) Data obtained by CCRL Approved Testing Facility with PC from TX
**) Data obtained with Swedish PC (CEM I, 42.5)

Results and observations.

- Setting time EMC70fa are line with PC (initial 2:40h and final 3:50h)

- No water reducing agent (superplasticizer) has been used for the mixture with water-to-binder ratio 0.42. Consistency: EMC70fa showed about 10-12% higher flowability in comparison with PC mortar with similar water content.
  This could have a very positive influence on workability of the concrete mixtures (reduction of water-to-binder ratio without slump loss)

- EMC70fa is very sensitive to the addition of superplasticizer. Introduction of superplasticizer in amount of 0.1% by binder weight leads to reduction of w/B to 0.38 with the same level of consistency/ flowability of the mortar. This translates in significant reduction or elimination of the superplasticizer used in concrete mixture without slump loss.

- Mortars with EMC70fa showed excellent finishing performance. Surfaces of samples were very smooth, without porosity, and look like a pre-polished.

- The above results show that EMC cement with 70% fly ash (Class F) provides significantly better one day results and comparable 7 day results with those of pure

Portland cement. Compressive strength after 28 days of curing depending of water-to-binder ratio either equal or higher than strength of pure Portland cement and significantly better than blend of Portland cement and 20% of fly ash introduced in a traditional way.

- As also confirmed by tests done by the same CCRL laboratory and the University of Texas, EMC will provide significant improvements in sulfate resistance and alkali-silica reactivity.

- Fly ash cannot be added in the concrete mixer.

TECHNICAL EVALUATION
OF
ENERGETICALLY MODIFIED CEMENT
(EMC)

ISG Resources, Inc.
Material Testing and Research Facility
A Cement and Concrete Reference Laboratory (CCRL) Approved Testing Facility

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Confidential Document

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Introduction

Energetically Modified Cement (EMC) technology was developed at Luleå University of Technology in Luleå, Sweden by Dr. Vladimir Ronin et. al. in the early 1990's. The EMC technology employs a mechano-chemical activation process to increase the reactivity of Ordinary Portland Cement (OPC) with high filler and pozzolan replacements.

The EMC technology consists of processing a blend of OPC and pozzolan through multiple high intensity grinding mills to impart increased surface activation of the OPC and pozzolan particles. The high intensity grinding is typically accomplished by multiple stages of vibratory or stirred ball mills. The grinding circuit and type of grinding mills are typically custom designed for the raw materials to produce EMC with performance characteristics equivalent to its parent OPC.

This technical evaluation was conducted on EMC material produced by Dr. Ronin at the EMC pilot plant in Luleå, Sweden. The material is a 50:50 inter-grind of TXI-Ordinary Portland Cement (OPC) and Reliant Energy's Limestone Power Station fly ash (LFA). The EMC produced using LFA is herein referenced as EMC_L. The reference OPC used to produce EMC_L is herein refer to as OPC_r. The physical and chemical characteristics of EMC_L are compare to that of OPC_r, LFA, and conventional (50/50) blend of OPC_r and LFA . The EMC_L performance in mortar and concrete mixes is compared to that of neat OPC_r and OPC_r with conventional pozzolan (LFA) replacements.

Physical Characteristics

A summary of the particle size analyses of the OPC_r, LFA, 50/50 mixture of OPC_r and LFA (Blend) and EMC_L are presented in Table 1. The analyses were conducted using the Horiba laser scattering particle size analyzer. The entire particle size distribution results are included in the attachment.

Table 1. Particle Size Analysis Results.

Parameter	***OPC_r***	***LFA***	***Blend***	***EMC_L***
Median Particle size (µm)	16.0	14.3	14.3	11.8
Specific Surface Area cm^2/cm^2	5624	6624	6075	7220
Min Particle size (µm)	1.5	1.3	1.3	1.5
Max Particle size (µm)	50	100	100	70
Less than 10-micron (%)	61%	38%	52%	63%
Retained on 325-Mesh (%)	5%	20%	12%	5%

The EMC grinding process was effective in reducing the coarse fraction of the Limestone fly ash. The percent of the Blend retained on 325 Mesh was decreased from 12% to 5% by the EMC grinding process. The LFA is characteristically coarse and makes a poor pozzolan as compared to other ashes in the area.

The EMC grinding process did not produce any super fine materials (i.e., less than 1 micron). However, the less than 10-micron fraction increased from 52% to 63%. The overall specific surface area, an indicator of cement and pozzolan reactivity, increased by 18% by the EMC grinding process.

Chemical Analysis

The chemical analyses of the OPC_r, LFA and EMC_L were performed using X-ray fluorescence in accordance with ASTM D-4326. The insoluble residue test was performed in accordance with ASTM C-114. The results of the chemical analyses are presented in Table 2.

Table 2. Chemical Analysis

Compound	***OPC_r***	***LFA***	***EMC_L***
CaO	62.4%	15.0%	40.9%
SiO_2	17.8%	49.4%	33.2%
Al_2O_3	4.0%	19.6%	6.3%
Fe_2O_3	3.9%	5.2%	4.1%
SO_3	3.2%	0.8%	1.6%
Na_2O	<0.1%	0.3%	0.1%
K_2O	0.3%	1.2%	1.2%
Insoluble Residue	0.52%	51.32%	21.68%

The insoluble residue results indicate that the EMC_L material is indeed derived from an approximately 50/50 blend of OPC_r and LFA.

Performance Testing

The EMC_L strength development performance relative to the OPC_r was evaluated in accordance with ASTM C-109, ASTM C-311 and ASTM C-192. For comparison with other benchmarks, mortar cubes were also made for compressive strength testing using OPC_r with conventional 20% and 40% limestone fly ash replacement. The water to cement ratio (W/C) and compressive strength in psi at various curing times are presented in Table 3.

Table 3. Mortar Strength Development

	W/C Ratio	*Compressive Strength in psi after*			
		1-day	*3-days*	*7-days*	*28-days*
OPC_r	**0.48**	**1492**	**3855**	**4353**	**5601**
EMC_L	**0.43**	**2138**	**3322**	**3945**	**5966**
80% OPC_r w/ 20% LFA	0.46	943	2957	3430	5195
60% OPC_r w/ 40% LFA	0.44	547	2185	2565	4294

The EMC_L made with 50/50 OPC_r and LFA showed about 40% higher strength after 24 hours than the reference OPC_r. EMC_L strength development lags slightly behind OPC_r at 3 and 7 days. However, the strength development after 28 days is equivalent to OPC_r.

EMC_L performed significantly better than portland-pozzolan blended cements with 20% and 40% fly ash replacements. The workability of EMC_L, which contains 50% fly ash, appears better than ordinary portland cement. The high fly ash loading allowed for a 10% reduction in water cement ratio, which translates into higher long-term strength.

The EMC_L strength development relative to the OPC_r was also evaluated using concrete cylinders. The concrete mix design parameters are presented in Table 4. The concrete strength development results are presented in Table 5.

Table 4. Concrete Mix Design Parameters

Parameter	***OPC_r***	***EMC_L***
Cement (% by weight)	13%	13%
Sand (% by weight)	38%	38%
Coarse Aggregates(% by weight)	45%	45%
W/C Ratio	0.67	0.66
Slump (inches)	2"	2"
Air Content (%)	2.0%	1.5%
Unit Weight (lb/cy)	3,974	4,126

Table 5. Concrete Strength Development

	W/C	*Compressive Strength in psi after*			
	Ratio	*3-days*	*7-days*	*14-days*	*28-days*
OPC_r	0.67	2318	3207	3832	4200
EMC_L	0.66	1996	2811	3438	4678
Percent of Reference		86%	88%	90%	111%

The concrete cylinder compressive strength results confirm the mortar cubes observations that EMC_L strength development lags behind OPC_r at 3 and 7 days but exceeds OPC_r after 28 days. This strength development pattern is typical of pozzolan rich cement.

The time of setting of EMC_L paste was compared to that of the reference OPC_r paste using the Gilmore apparatus according to ASTM C266. The paste consistency was verified using the Vicat needle per ASTM C187. The time of setting results are shown in Table 6.

Table 6. Time of Setting of Paste

	OPC_r	*EMC_L*
Water / Cement Ratio	0.24	0.22
Vicat Needle reading	9	9
Initial Set Time (hours)	2:29	2:26
Final Set Time (hours)	3:33	3:41

The set behavior of EMC_L paste is very similar to that of the reference OPC. Conventional portland-pozzolan blended cements have typically longer set times; 3 to 5 hours for initial set and 5 to 7 hours for final set.

The sulfate resistance and Alkali-Silica Reactivity (ASR) of EMC_L relative to the reference OPC_r were evaluated per ASTM 1012 and ASTM 441, respectively. The change in length of mortar bars exposed to sulfate solution and the maximum permissible values for six specimens (each) are presented in Table 7.

Table 7. Sulfate Resistance of Mortars

	TXI-OPC$_r$	*EMC$_L$*
% Change in Length after 1 week	0.006	0.006
% Change in Length after 2 weeks	0.012	0.011
% Change in Length after 3 weeks	0.013	0.011
% Change in Length after 4 weeks	0.013	0.011
Maximum Permissible Values for	*Portland Cement*	*Blended Cement*
(Average of 6 specimens) %	0.012	0.041

The mortar bars made with EMC_L have a slightly improved sulfate resistance over OPC_r. The expansion after 4 weeks was roughly one fourth lower than the maximum permissible level for blended cement.

The mortar bars made with EMC_L have a considerably better resistance (92% improvement) to alkali-silica reactivity than OPC_r mortar bars. The comparative change in length results after two weeks is shown in Table 8.

Table 8. Alkali-Silica Reactivity of Mortars

	OPC$_r$	*EMC$_L$*
% Change in Length after 2 weeks	0.026	0.002

Conclusions

The strength performance at 28 days of the EMC_L containing 50% class F fly ash (Limestone, Texas) and 50% ordinary portland cement (TXI) is comparable to the performance of the reference portland cement. There is no drastic reduction in the particle size using the EMC grinding technology. The workability and water requirement of EMC is better than that of the OPC. The setting time of EMC is very similar to that of OPC, which is significantly shorter than pozzolanic blended cements. Mortar made with EMC has much lower alkali-silica reactivity in comparison with the reference portland cement. The use of EMC may also improve the sulfate resistance of the mortar. No economic evaluations were performed as part of this technical study.